Microlensing events from galactic globular clusters

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We present an analysis of the large set of microlensing events detected so far toward the Galactic center with the purpose of investigating whether some of the dark lenses are located in Galactic globular clusters. We find that in four cases some events might indeed be due to lenses located in the globular clusters themselves. We also give a rough estimate for the average lens mass of the events being highly aligned with Galactic globular cluster centers and find that, under reasonable assumptions, the deflectors could most probably be either brown dwarfs, M-stars or stellar remnants.

1. Introduction

Globular cluster could contain a sizeable amount of dark matter in form of brown dwarfs or low mass stars. This is still an open issue and a possible way to test this is to use microlensing observations Refs. 1–3. The idea is to monitor globular clusters in front of rich background fields of stars of the galactic bulge. In this case, when the lens belongs to the cluster population, its distance and velocity are roughly known. This way it is possible to get a more accurate estimate for the lens mass. Such a study has already been performed [2,3] and some events were found which might be associated with lenses in globular clusters Refs. 2–4.

We analysed the possible MACHO content in a large set of Galactic Globular Clusters (hereafter GGCs) some of which are highly aligned with a non negligible number of microlensing events detected toward the Galactic Center (hereafter GC). The data set included 4697 microlensing events detected in the last years by the MACHO, OGLE, and MOA collaborations in direction of the GC. In our analysis we focused on the configuration in which the lens is hosted in a GGC and the source is located either in the Galactic disc or bulge.

2. Results and conclusions

Aiming at discriminating among events due to lenses hosted either in GGCs or in the Galactic bulge/disc, we first made a rough selection of events being aligned with a GGC. In particular, for every given GGC, we considered a sphere of radius r_t (corresponding to its tidal radius), centered at the GGC center, and we selected, as a first step, only the events being included in one such contour. By doing so, out of the original 4697 events, we were left with 118.

The GGCs aligned with at least one event are given in Table 1. Some properties are also reported, such as the tidal and the core radius, the distance from the Sun [5] and the number of included events. The different core radii and central densities explain the large variations of the optical depth among the GCCs.

Due to the GGC structure, we expect the predicted number of events to be the largest toward their centers and to decrease as we move toward their borders. Since the alignment between an event and a projected cluster contour does not assure that the deflector belongs to the GGC, this alignment possibly being accidental, we made a further, rough selection and considered only the events being included in the projected contour of a sphere centered at a GGC center and of radius $r_i = 2 \times r_t/5$ (this including on average 90% of the total cluster mass). We then distinguished between *inner* and *outer* events, the former being inside r_i and the latter being included in the circular ring of internal radius r_i and outer radius r_t. By doing so, we assumed all the outer events

Table 1. GGCs being aligned with at least one detected microlensing event. For each of them the number of aligned events N_{tot} and the corresponding average duration $< t_E >$ (in days) is given. For every GGC, r_t is the tidal radius (in pc), r_c is the core radius (in pc), r_{sun} is the distance of its center from the Sun (in kpc) and τ is the optical depth toward its center in units of $f \times 10^{-5}$, f being the fraction of dark matter mass in the GGC.

Cluster ID	r_{sun}	r_t	r_c	τ	N_{tot}	$< t_E >$
Pal 6	5.9	14.3	1.13	0.24	2	76.3
Terzan 9	6.5	15.5	0.06	0.78	2	17.8
NGC 6522	7.8	37.3	0.11	6.06	36	16.8
NGC 6528	7.9	38.1	0.21	1.01	38	25.2
NGC 6540	3.7	10.2	0.03	23.74	29	22.8
NGC 6553	6.0	14.2	0.96	1.01	7	43.0
NGC 6558	7.4	22.5	0.06	7.20	1	24.5
NGC 6624	7.9	47.2	0.14	4.43	1	223.0
NGC 6656	3.2	27.0	1.32	0.75	2	112.7

to be due to Galactic bulge/disc deflectors (this possibly underestimating the events due to GGC lenses), whereas we left open the possibility that among the inner events some could still be attributed to bulge/disc deflectors. At the end we are left with 28 inner events, among which 7 (17/4) have been detected by the MACHO (OGLE/MOA) collaboration.

Table 2. GGCs with inner events. For each of them N_{in} is the number of events inside a projected radius $r = 2 \times r_t/5$ and, for this subset of aligned events, $< t_E >$ is the mean Einstein time (in days) and $< m >$ is the average predicted lens mass in units of solar masses. N_{GGC} (N_{BD}) is the number of events, out of N_{in}, that we expect to be due to GGC (Galactic bulge/disc) lenses. Γ_{exp} is the expected event rate in units of $f \times \mu_o^{-1/2} \times 10^{-3}/year$, while n_{GGC} is N_{GGC} per unit area (in degree^{-2}).

Cluster ID	N_{in}	$< t_E >$	$< m >$	N_{BD}	N_{GGC}	Γ_{exp}	n_{GGC}
NGC 6522	8	13.1	1.63	4.1$\pm$ 2.0	3.9	0.66	51.4
NGC 6528	7	13.0	2.98	4.9$\pm$ 2.2	2.1	0.09	27.5
NGC 6540	7	17.2	0.06	4.2$\pm$ 2.0	2.8	1.56	112.3
NGC 6553	4	35.7	0.62	0.6$\pm$ 0.8	3.4	0.08	185.4

An estimation of the predicted number of events, N_{GGC}, due to MACHOs in a given GGC, can be roughly made as follows. Assuming that all the outer events are due to Galactic bulge/disc lenses, we calculate how many such events, N_{BD}, are expected in the inner region of a GGC contour assuming that the number of events is proportional to the covered area and that the background source distribution is uniform inside every GGC contour. Thus we assume that the microlensing rate for Galactic bulge/disc events is constant over the entire small area within the tidal radius of the considered globular cluster. By doing so, N_{BD} is simply proportional to the monitored area. Clearly, also with these assumptions, which are reasonable, given the very small area considered, one expects fluctuations in the number of events in a given area. We assume the fluctuations to follow Poisson statistics, in which case they are given by $\sim \sqrt{N_{BD}}$. By doing so, for every GGC considered, N_{GGC} turns out to be around 2-4 per cluster (see Table 2) and in two cases this number is larger than the estimated fluctuation of N_{BD}. Given these numbers we cannot claim for any clear evidence of lenses hosted in GGCs. Nonetheless,

it is remarkable that for the 4 cases considered the value of N_{GGC} is positive and most probably underestimated, since the assumption that all the events lying in the outer ring are due to bulge/disc deflectors possibly overestimates N_{BD}.

Assuming that the deflector is a GGC MACHO, we can estimate its mass through the relation $R_E/t_E = v_r$, where v_r is the lens-source relative velocity orthogonal to the l.o.s., t_E is the event Einstein time and R_E is the Einstein radius. For v_r we adopt the value of the proper motion of the considered globular cluster as given in the literature. As reported in Ref. 5, the mean GGC tidal radius is of the order of tens of pc, this making the GGC extension relatively small compared to the average lens distance from Earth or the source distance (of the order of kpc), since we are assuming Galactic bulge/disc sources and the GGCs are kpcs away from the Sun. For this reason, we make the simple assumption that in a given GGC the MACHOs are all at the same distance from the Sun (r_{sun}, as given in Table 1). Table 2 shows, for the whole subset of inner events, the predicted deflector mass in units of solar masses, $< m >$, obtained with these assumptions. The resulting average lens mass gets values in the range $\{10^{-2}, 10\}$, suggesting that the involved deflectors are possibly either brown dwarfs, M-stars or stellar remnants. Moreover, Jupiter-like deflectors are not definitively excluded, since, already a small increase on D_{os} can substantially reduce the predicted lens mass.

The average expected lens mass has been drawn from the set of inner events, some of which being possibly not due to GGC MACHOs. This source of contamination should be removed before one makes any prediction, but since we are not able to do such a distinction, the average values on the overall inner sample can be taken as a first crude approximation.

Also given in Table 2 is the number of expected events toward the GGC centers, Γ_{exp}, as calculated through formula (36) of [3], where it is assumed that all the lenses have the same mass, μ_o, in units of solar masses and that their distribution is very narrow with respect to that of the source population. Γ_{exp} is given in units of $f \times \mu_o^{-1/2} \times 10^{-3}/year$, f being the fraction of dark matter (in form of brown dwarfs, dim stars or stellar remnants) in the cluster. For a typical value of $10^2 - 10^3$ monitored source stars behind a GGC (this number depending also on the GGC extension) and an observation period of ~ 5 to 10 years, we expect at most between half an event and a couple of events toward each GGC depending also on the value of f, in reasonable agreement with the results of Table 2.

Clearly, the expected number of events, and thus the rate, is certainly quite small so that more observations are needed. A possible strategy would be to survey systematically during many years the line of sight comprising the four globular clusters which we analysed. In spite of all the mentioned limitations, we believe that our results, although not conclusive, suggest that some events might indeed be due to lenses located in globular clusters.

References

1. Paczynski, B. 1994, Acta Astronomica, 44, 235
2. De Luca, F., Jetzer, Ph., 2008, Int. J. Mod. Phys. D17, 2305
3. Jetzer, Ph., Strässle M., Wandeler, U. 1998, A&A, 336, 411
4. Sahu, K.C., Casertano, L., Livio, M., et al. 2001, Nature, 411, 1022
5. Harris, W. E. 1996, AJ, 112, 1487